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Moving toward 1.5°C of warming: implications for climate adaptation strategies

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The literature on adaptation to climate change indicates that limiting global warming to 1.5°C or less would reduce damages relative to higher magnitudes of warming, and require less adaptive effort particularly by lessening the risk of extremes and reducing the potential need for transformative adaptation. Smaller climate change nevertheless poses risks of significant impacts, dislocation and adaptation costs in particularly exposed and vulnerable places. Climate change will also vary across space, and smaller, slower average change will likely still result in larger, rapid change for some systems and places (e.g. the Arctic and oceanic islands). Furthermore, non-linearities and power–law relationships among components of the earth's climate system mean that the potential for passing thresholds where parts of the system exhibit extreme behavior cannot be confidently excluded from a 1.5° scenario. The potential for overshoot in a climate that eventually equilibrates at 1.5°C or less above pre-industrial also means that anticipatory adaptation planning efforts should not be relaxed. Yet, taken together, the literature suggests that reactive adaptation has a better chance of keeping pace with the lower range of warming in many places and production systems (although not necessarily all), and could reduce though not eliminate the risk of large damages and adaptation costs in exposed and vulnerable places. Anticipatory adaptation investments, however, can be justified even for low levels of climate change and appear less sensitive to the projected magnitude of change in climate, and driven more by uncertainty in future emission and climate trajectories.

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Introduction

The Paris Accord on climate change included the challenge of 'pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels" which "would significantly reduce the risks and impacts of climate change' [1••]. This paper explores the implications of this policy target for adaptation both in reaction to a changing climate and in anticipation of future change. The literature on adaptation to climate change indicates that limiting global warming to 1.5°C or less would reduce damages relative to higher magnitudes of warming, and require less adaptive effort particularly by lessening the risk of extremes and reducing the potential need for transformative adaptation. Smaller climate change nevertheless poses risks of significant impacts, dislocation and adaptation costs in particularly exposed and vulnerable places. And those impacts may propagate through global trade, migration and other mechanisms, to have wider effects. Climate change will vary across space, and smaller, slower average change will likely still result in larger, rapid change for some systems and places (e.g. coral reefs, the Arctic, and oceanic islands) [2,3•,4,5•]. Furthermore, non-linearities and power-law relationships among components of the earth's climate system mean that the potential for passing thresholds where parts of the system exhibit extreme behavior cannot be confidently excluded from a 1.5° scenario [6•,7•,8]. The potential for overshoot in a climate that eventually equilibrates at 1.5°C or less above pre-industrial also means that anticipatory adaptation planning efforts should not be relaxed [9]. But the many different adaptation strategies, and their differential sensitivities to uncertainty, potential over-shoot in the transient global equilibrium temperature, and extreme events, complicate the calculus of adaptive effort associated with a 1.5°C target. The adaptation literature going back several decades suggests that reactive adaptation benefits from slower and lower magnitude change ([5•], pp. 21–25). We assert that prudent anticipatory adaptation can reduce net adaptations costs relative to an approach of only reacting to climate change regardless of the eventual change in climate. However, adaptation plans made in advance of climate change are more sensitive to uncertainty in future emission and climate trajectories, uncertainties that remain even as mitigation targets shift to lower warming.

Insights from the impacts, adaptation, and vulnerability literature about a 1.5°C world

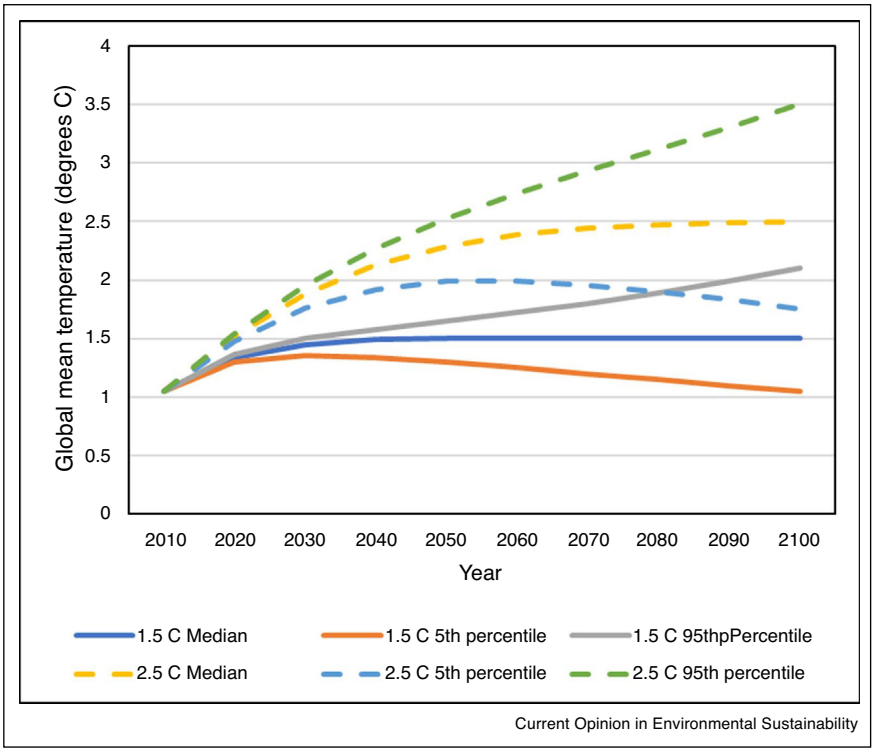
A climate that warms 1.5°C above pre-industrial should, ceteris paribus, cause less impact than the 2–3.5°C warming often considered in impact studies, and it should

demand less adaptive effort. Generally, the larger the magnitude of warming the greater the net damages (e.g. [5•,10], and larger damages will result in larger adaptation costs. More warming will, for example, result in more rapid sea level rise, requiring higher and more expensive sea walls, more extensive elevation of valuable low-lying assets, and more widespread dislocation. More warming would also intensify extreme events such as floods and droughts, also resulting in larger adaptation costs [11•]. Some sectors, places and people would still face great risk even in a 1.5°C warmer world; indeed, the move toward a 1.5°C target was in recognition of threats to the most vulnerable places and populations, including the 'least developed countries and small island developing States' [1••]. Even at this lower rate of change, some individuals and communities may be forced into transformative adaptation such as relocating or fundamentally changing land uses [12•]. Yet some sectors in some places may find that mitigation to a 1.5°C target reduces the magnitude or can change the scope of adaptation. For example, the combination of carbon fertilization and expanded crop zones can result in net gains in agricultural productivity when climate change is limited to 2°C or less in some locations such as in higher latitudes [13]. Even in those locations is possible that changes such as in pests, soil productivity, and extreme events such as drought could limit or offset the benefits from carbon fertilization and longer growing seasons. Still, the effects of smaller rates of warming on regional to global food security remain uncertain, and negative effects are likely to ripple through the global system [14•].

Climate trajectories for the 1.5°C target

Given the sensitivity to rate of change cited in the adaptation literature, it is useful to envision possible emissions pathways with associated climate change trajectories [9]. Note that while the policy goal is set to a global temperature so that it can be linked to greenhouse gas concentrations and the emission reductions needed to meet the goal, climate is experienced by people and resource systems through tangible conditions and events such as seasonal swings and extreme events (e.g. heavy precipitation). The link between global temperature and tangible climate outcomes in specific regions and sectors was made via the 'reasons for concern' and regional assessments [6•]. But as with mitigation targets, adaptation needs have also been abstracted to global temperature, and in that case both reactive and anticipatory adaptation would be informed by observed and projected contemporaneous temperature rise, not estimates of abstract long-run equilibrium temperature. Figure 1 displays three transient temperature trajectories (5th

Figure 1



Temperature trajectories consistent with limiting median transient temperature to 1.5 and 2.5 °C. Uncertainty in the transient temperature trajectories results from uncertainty in sinks and climate sensitivity in the link between cumulative emissions and transient temperature. Derived from Ref. [9].

percentile, median, and 95th percentile) for emissions trajectories aimed at 1.5°C and 2.5°C targets [9]. Each temperature trajectory reflects the uncertain relationship between transient global mean temperature and contemporaneous cumulative emissions [15••,16,17], including uncertainty in our knowledge of the behavior of sinks in warmer climates and of climate system sensitivity to the amount of energy added to the earth system by increased GHG concentrations.

The pace along the paths associated with the 1.5°C target is demonstrably slower than those for the 2.5°C target, so it is not difficult to believe that the net costs of reactive adaptation would be smaller; less change implies not only lower risk to key sectors and systems but allows for adaptation to reduce risk from high to medium in most areas as assessed by the Intergovernmental Panel on Climate change (IPCC) Working Group 2 [5•]. Figure 1 additionally shows that two of the three 1.5°C trajectories (as well as the 5th percentile future for 2.5°C) turn nearly horizontal around the middle of the century. These trajectories thus display a temperature future with a relatively stable maximum temperature that will allow adaptation agents to become comfortable with a 'new normal'. Reactive adaptation could, at that point, begin to adopt new standards proven in practice knowing that the important manifestations of climate are, from year to year, being drawn from the same static distribution.

Studies of impacts and adaptation across a range of warming

Applying the simple notion that larger assessed impacts demand larger and more expensive and challenging adaptation efforts, the full range of IAV literature, which now spans some 40 years [18], can illuminate adaptation implications of the 1.5°C target. Early studies tended to postulate modest change compared to more recent literature, such as 2°C warming and 10% less precipitation in the Colorado River [19], and 1°C warming in the U.S. 'corn belt' which would shift it roughly 100 miles northward [20]. Other early work employed historical and paleoclimate analogs such as the 1930s droughts in North America [21] and the medieval warm period and Little Ice Age in Europe [22]. Many of these early studies concluded that modern occurrence of such past anomalies would have only modest impacts due to advances in technology [23]. A study of the recurrence of the 1930s dry/warm spell on circa-1990 U.S. agriculture, water, forestry and transportation, found that adaptive capacity on hand could mostly negate the impact. This capacity was achieved at some cost, of course, which was more difficult to discern but was estimated to be relatively minor for a wealthy, industrialized country like the U.S. [23,21]. Analysts were quick to point out that effects of even modest climate change would be greater in the developing world and that the effects of, and ability to adapt to, more extreme climate change, outside the realm of historical experience, could not reliably be predicted for developed or developing economies ([23], p. 635).

By the third and fourth IPCC assessments, concern about greater rates of warming gained credence, as did concern about possible tipping points [8] and thresholds beyond which severe climate change occurred. Impacts and adaptation analysis reflected increasing concern about warming in the range of 3°C and even beyond [24•,25,26]. Analysis at the upper end raised concerns that climate change could simply outstrip the rate and capacity of adaptation, potentialities framed as 'Reasons for Concern' (e.g. [6•,7•]) and 'Limits to Adaptation' [27]. To accommodate this concern, the IAV literature included attempts to develop a comprehensive loss or damage function for a larger range of warming (e.g. [28,29,30•]). Aggregate and comprehensive loss calculations also encouraged several efforts to calculate the social cost of carbon (e.g. [31,10]), and to assess the benefits of lower emission pathways and lower warming, for example, the AVOID program in the United Kingdom [32], and BRACE: Benefits of Reduced Anthropogenic Climate Change [33]. Such efforts should eventually provide more robust estimates of the benefits of the 1.5°C target and of its remaining costs.

Any generalized loss function is problematic, necessarily understating impacts in some regions and sectors, and over-stating it in others [30•], but a loss curve does invite inspection of its lower ranges to get a glimpse of a 1.5°C world. The 1.5°C target is meant to keep places and societies below the point where losses from regional to local climate conditions start to increase substantially. Thus, the literature attends to adaptation needs that reflect regional and individual exposure and vulnerability. Places such as island nations [3•] and regions where agricultural production is already near an upper temperature limit [34•], would experience greater loss and adaptive effort than broadly aggregate or global losses would indicate. This range is illustrated in ([5•], pp. 21–25), which nevertheless inculcates an argument about a world that warms only 1.5°C: it is, with regard to rate of change, a more familiar place. Humanity has experienced roughly 0.8°C warming in the last century [24•], and the impacts, increased disasters, and growing vulnerability over this period [11•] provide some insight into the risks associated with further change even if global warming is stabilized after another .8° degrees or so. However, additional warming above what has been observed can trigger more frequent and severe extreme events and pose risks of crossing thresholds.

Assessment challenges at 1.5°C

One challenge in extracting adaptation lessons for 1.5°C from the literature is the tendency to project impacts without accounting for adaptation or not making explicit whether impacts are calculated as un-adapted or net of adaptation. And, as noted earlier, some studies start

assessing impacts and adaptation at around 2°C [14•] This has hampered efforts to assess net impacts and to compare effects along the full range of warming. In an extensive review of climate change impacts across a wide range of warming, Warren [35•] concluded, 'adaptation is treated superficially and inconsistently in the literature and assumptions made are often poorly documented' (p. 94). A recent effort to calculate the social cost of carbon dioxide also concluded that adaptation costs are difficult to assess and poorly handled in impact models [10]. Evolution of the UNFCCC framework for 'Loss and Damage' reflects this challenge, in some instances defining loss and damage as impacts that cannot be reduced by mitigation or adaptation, and in other cases as all direct and indirect losses from weather and climate extremes [36].

The literature also identifies barriers to adaptation that not only complicate response to small warming but may even have squelched adaptation to the current climate, the so-called 'adaptation deficit' [37•,38]. Adaptation deficit is framed in two main ways: (a) as under-adaptation to the baseline climate, and especially its extremes [11•,39], supposing that better adapting to current extremes would offer a 'no-regret' effort that pays off even without future climate change, and (b) as lagging adaptation to recent climate change [30•,31]. An effective 1.5°C limit would provide more room for addressing the current adaptation deficit, that is, it enhances the logic of preparing for climate change by better managing current variability and extremes, as suggested in the IPCC special report on extremes [11•], and in the Sendai Framework for Disaster Reduction [40]. Perhaps by raising the potential for 'low regrets' approaches, the target would also encourage risk management of local-regional hot spots of climate exposure and vulnerability (as mapped, e.g. by [4,34•]), and these may be amenable to impact reduction by current methods rather than transformational adaptation. The 1.5°C target, by reducing the costs of responding to a warming climate relative to other demands on society, along with disaster reduction assistance, might also allow for more attention to other social-economic trends that are worsening hazard risks regardless of climate change. Climate change adaptation could be better articulated with the Sustainable Development Goals [41] and poverty eradication, and the Sendai Framework for Disaster Reduction [40].

Insights about anticipatory adaptation strategies for a 1.5°C world

A 1.5°C warming is expected to lead to lower global net adaptation costs, mainly as a result of lower *reactive* adaptation costs, that is, costs that are incurred in response to observed climate changes and impacts. However, the focus of adaptation policy-making has typically been on *anticipatory* adaptation or 'adaptation planning' (e.g. [42•]), including measures that can be adopted in advance to prevent adverse impacts from occurring or to enhance response capacity to reduce the time and cost of future reactive adaptation.

Anticipatory adaptation planning

Many characteristics of planned adaptations can be identified to support a hypothesis that a shift from expectations of 2°C warming, to 1.5°C warming would not result in substantial reductions in anticipatory adaptation costs. This is for several reasons. First, many anticipatory adaptations would not be sensitive to the projected magnitude of change in climate either because they have such characteristics as reducing sensitivity of a system to climate risks, enhancing adaptive capacity, or introducing flexibility (which can increase the resilience of systems to respond to climate shocks). Management changes in several sectors, such as efficient use of water resources [43], reduced stress on human health [44•], and land use planning and early warning systems for hazards [11•], fit this profile. They provide benefits under current climate and provide benefits under different climates; that is, they are designed to reduce current and future adaptation deficits. In addition, many actions proposed for climate change funding do not directly address climate change risks. For example, approximately three-fifths of the funding for proposed National Adaptation Programmes of Action (NAPAs) could be considered investments in development, not adaptations designed specifically to address climate change risks [45]. Such investments increase capacity for adaptation, but are not scaled to the magnitude of climate risk. In this way, adaptation to climate change can be seen as part of the larger rubric of sustainable development [46] and not solely tied to climate change adaptation.

Other anticipatory adaptation must, however, addresses uncertainty about the magnitude and characteristics of long-term future climate change. While there is virtually no doubt that the earth's climate will continue to warm, there is uncertainty about the magnitude of such warming, the speed and intensity of changes in regional climate, and how climate variability will change (e.g. [24•]). In light of such uncertainty, planning for a specific magnitude of climate change (e.g. a 1-meter sea level rise) risks doing more than necessary should sea level rise be less than a meter or having insufficient adaptation plans in place should sea level rise be greater. For anticipatory adaptations to be likely to succeed given the uncertainties about future climate change, they should therefore be effective across a range of possible future climates. In the early adaptation literature, the strategy of *flexibility* was emphasized (e.g. [47•]). Adaptations would have the flexibility to be amended as future conditions unfold. Recent work describes a mixture of robustness and flexibility that is relatively insensitive to the expected range of future change [48,49]. Ideas have been offered to further refine this approach to anticipatory adaptation. For example, robust decision-making provides minimum regrets

over a wide range of climate change scenarios (e.g. [50•]) by building large capacity into systems. The explicit intention is to make systems function over a wide magnitude of climate change, but the added capacity may come with significant costs. The emerging strategy of multiple adaptive pathways that can be altered in the future as the actual climate unfolds, further disentangles adaptive planning from specific projections of future climate conditions [51,52].

Resilience, the capacity of municipalities and other entities to recover from stresses and shocks [53], is a critical indicator of human attempts to reduce future risks from climate [46]. Such stresses and shocks are not limited to climate, but can include other natural hazards and socio-economic stresses [47•]. Investments in resilience should have benefits across multiple risks and different magnitudes of risk. This is not to say that such investments will be equally effective at different magnitudes, but that the planning design of such adaptations is not tightly scaled to anticipated change in climate.

Risk and uncertainties

Figure 1 sheds some light on the effect of moving to a 1.5°C target in anticipatory adaptation in projects and plans that are frequently characterized by time horizons of 40 years or more. The lower temperature trajectories are not only flatter; they are closer together in the second half of the century. This is a benefit of lower emissions that could play a significant role in evaluating risk to infrastructure and other construction projects that should, in their very inception, incorporate flexible or robust adaptation options to a credible range of possible futures (here calibrated in temperature). It follows that fewer or smaller options might therefore be considered when confronting lower temperature futures. But completely ignoring the higher tails would be risky: the 95th percentile path for 1.5°C nearly matches the 5th percentile path for the 2.5°C world. Recognizing that uncertainty about socio-political-economic futures calibrated in, for example, rates of economic growth and/or adherence to (voluntary) global mitigation targets is perhaps larger than uncertainty in earth systems behavior (the range comparison just noted shows this starting in 2050), it follows from the natural science alone that betting on a 1.5°C future and ignoring a 2.5°C future would be unwise; or, talk of meeting a 1.5°C target should not deflect much attention from the 2.5°C target (which may actually turn out to be 3 or 4 degrees C across this century).

Given the current inertia in greenhouse gas emissions and response of the earth system, it is quite possible that a 2°C stabilization trajectory would entail global mean temperatures rising by more than 2°C before reversing and settling into a long-term 2°C target (or 1.5°C, for that matter). This 'overshooting' is illustrated modestly by both 5th percentile runs in Figure 1, for example. Given a more stringent target and the immediate need for greater net emissions reduction, it is quite reasonable to expect that the magnitude of a temperature overshoot would be larger along a 1.5°C stabilization pathway than along a 2°C alternative. This is in large measure because the temperature trajectories for any cumulative emissions and temperature target track closely together for decades due to historical cumulative emissions. Thus, anticipatory adaptation must to plan for the possibility that temperatures will exceed the target (whether it is 1.5 or 2°C or more) in ways that do not differ over the short term. This is another reason for guarding against paying too much attention in the short-term to the prospect of a lower temperature future in the transition to equilibrium, because the difference in peak warming under the two stabilization targets may be so small as to result in little difference in anticipatory adaptations.

Conclusions

There is little doubt that the effort and cost to adapt to 1.5°C will be lower than the cost to adapt to warming in the range of 2–3.5°C often examined in the impacts and adaptation literature. Limiting human forcing of the climate to such a magnitude may keep the current rate of warming from accelerating, thus reducing the likelihood of larger changes in climate elements critical to social and ecological well-being. The adaptation literature has long held that slower and lower magnitude change allows for less disruptive reactive adaptation. Climate change of course will vary across space, and smaller, slower average change will likely still result in larger, rapid change for some systems and places (e.g. the Arctic and oceanic islands). Furthermore, non-linear relationships among components of the earth's climate system mean that the potential for passing thresholds where parts of the system exhibit extreme behavior cannot be confidently excluded from a 1.5° scenario. The potential for overshoot in a climate that eventually equilibrates at 1.5°C or less above pre-industrial also means that anticipatory adaptation planning efforts should not be relaxed. Yet, taken together, the literature suggests that reactive adaptation has a better chance of keeping pace with the lower range of warming in many places and production systems, and could reduce though not eliminate the risk of large damages and adaptation costs in exposed and vulnerable places. But strategies for anticipatory adaptation to climate change do not typically distinguish between magnitudes of warming, particularly at the low end, and adaptation planners may find it prudent to plan for the possibility of more warming. Thus, while a more aggressive mitigation of GHG emissions, if successful, will lower the costs of reactive adaptation, it is not clear that the anticipatory adaptations needs will be much reduced.

Conflicts of interest

None declared.

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